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PRELIMINARY LUNAR EXPLORATION PLAN OF THE MARIUS HILLS REGION OF THE MOON

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PRELIMINARY LUNAR EXPLORATION PLAN OF THE MARIUS HILLS REGION OF THE MOON

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INTRODUCTION

This report presents a preliminary Lunar Exploration Plan (LEP) for the Marius Hills region of the Moon. The Marius Hills region is one of the six sites considered by the GLEP site selection group as a candidate for manned exploration using mobility systems allowing a radius of operation of at least 5 km. The 3-day mission considered for the Marius Hills region is based on the use of one lunar roving vehicle (LRV) and two lunar flying units (LFU's) and allows for four extravehicular activities (EVA's) of 3 hours each.

Effective planning for geologic field investigations on a lunar mission requires detailed consideration of 1) the best available information on the geology of the site to be explored and on relevant regional geology, and 2) operational and performance characteristics of launch vehicles, mobility systems, instrument systems, and communication systems. Factors such as stay time, payload, and range are especially important. Inasmuch as our knowledge of lunar geology and our concepts of lunar surface operational support systems are still evolving, clearly lunar exploration plans must be continually refined and updated.

Operational concepts and assumptions in this report are the best estimates currently available from the Manned Spacecraft Center. The geologic data used in preparing the preliminary mission plan are based on geologic maps made specifically for this purpose by the U.S. Geological Survey. Continued geologic mapping of the area at increasingly larger scales, and refinements in operational concepts, will undoubtedly necessitate changes in the present plan. Nonetheless, this plan illustrates in broad outline what can be accomplished scientifically with two LFU's and an LRV during a 3-day manned mission.

The traverses are designed to enable sampling of the many features within the landing area that are inferred to be of volcanic origin and controlled by a major linear rupture in the lunar crust. The geophysics experiments will provide data bearing directly on the geology of the region and were integrated within the framework of the geologic traverse requirements. The use of active seismic charges and geophone arrays along lines 7 km long perpendicular and parallel to the axis of the inferred regional structure should, along with largely automatic magnetic and gravity surveys, provide significant information on subsurface structures to depths of 1 to 2 km. It should be possible to relate this geophysical data to the surface geology and, in a broad sense, to the solid-body geophysical data obtained from the ALSEP instruments deployed in this and other missions.

The authors are indebted to E. Simmons of Massachusetts Institute of Technology and to R. Kovach of Stanford University for assistance in planning the geophysical sections of the mission plan. The assistance was in the form of telephone conversations, and the authors therefore assume full responsibility for any discrepancies in the geophysics plans.

REGIONAL SETTING, SIGNIFICANCE, AND GEOLOGIC MAPPING

The Marius Hills volcanic complex, near the center of Oceanus Procellarum, is one of the most concentrated and varied arrays of probable volcanic features on the Moon. Intensive study of the area, using telescopic data, began 4 years ago and was followed by analyses of the excellent photographs obtained by Lunar Orbiter II, IV and V (McCauley, 1965, 1967a, b, c). Two new preliminary geologic maps were prepared specifically for this surface exploration study (pls. 1-3). The small-scale map (pl. 1) was prepared from stereoscopic moderate-resolution Orbiter V coverage and was plotted on frame M215. The large-scale map (pl. 2) was prepared from the high-resolution coverage of the northwest corner of this frame and is roughly centered on a geologically varied area considered to be representative of the entire volcanic complex.

The Marius Hills volcanic complex lies athwart one of the longest continuously developed ridge systems on the Moon. This system is near the center of and parallel to the major axis of Oceanus Procellarum, the largest continuous expanse of maria on the Moon, which in contrast to the circular mare-filled basins is crudely elliptical in shape. The Marius Hills region, the Aristarchus Plateau, and the Rümker Hills all lie along this "mid-oceanic" Procellarum ridge system and are similar in certain respects to terrestrial oceanic volcanic plateaus such as Iceland and the Azores. On Earth, plateaus of this type are located along major rift zones commonly attributed to rising convection currents within the Earth's mantle. Its unusual regional setting, therefore, raises the question as to whether the Marius Hills volcanic complex is indeed the product of deep-seated lunar convection. The range in form of probable volcanic features raises the additional question of whether magmatic differentiation has occurred on the Moon. If so, how did it occur and what are the end products? Are this and other mid-Procellarum plateaus the final differentiation products of the more primitive basaltic magmas that initially filled the mare basins? Even if such questions are only partly answered, our understanding of lunar volcanism and its role in surface evolution will be greatly improved. The Marius Hills is ideal, from the standpoint of logistic ease and potential scientific return for a manned lunar landing designed to investigate lunar volcanic problems.

Small-Scale Geologic Map

Plate 1 shows the regional relations of the most promising landing area in Marius Hills that is covered by high-resolution photography. Two prominent sinuous rilles occur in the central part of the area, one of which is unusual because it exhibits a rim. At this juncture, however, neither can be effectively studied without compromising the main theme of the mission proposed--i.e., lunar volcanism. Furthermore, other missions will probably be devoted to the rille problem (e.g., mission to Hadley Rille area). Plate 3 describes the units mapped and places them in relative stratigraphic sequence. Preliminary topographic profiles of selected features in the region of strongest stereoscopy were measured parallel to framelets by Gary Nakata of the U.S. Geological Survey. Unfortunately, these profiles lie outside the region of primary geologic interest; however, they are useful for estimating maximum heights and average slopes across features that are similar to those within the Apollo target zone. The low domes are generally 50-100 meters high. The steep domes rise as much as 200-250 meters above the surrounding plains, and the highest punctured cones may be about 300 meters above the plains. A slope analysis of the profiles over a slope length of 30 meters indicates an arithmetic mean of 8° with no correction for included rilles and large craters.

Large-scale Geologic Map

The preferred surface exploration site lies within the area covered by the 1:25,000-scale geologic map (pl. 2). A variety of punctured cones, low domes, steep domes, and small bulbous domes (not shown on the small-scale map), which are considered representative of the volcanic complex as a whole, are shown on plate 2. Bedrock exposures and scattered block fields are numerous throughout the area. Two possible landing points are shown at A and B. Only the northernmost has been studied in terms of exploration potential.

The major geologic features that are within 5 km (maximum operating radius in this mission plan) of the proposed landing sites are: 1) gently rolling cratered plains similar in texture to the maria but elevated at the northern edge of the complex along an irregular scarp about 100 meters high, 2) numerous low domes 50-100 meters higher than the surrounding plains with convex-upward slopes, 3) steep-sided domes with a rough and intricate surface texture, generally perched upon low domes, 4) steeply convex upward or bulbous domes that are smooth and generally equidimensional in plan, 5) steep-sided cones with one or more linear summit depressions, 6) narrow steep-sided ridges elsewhere superposed on the broader, lower ridges of complex form typical of the maria, 7) the usual array of probable impact features including small bright-halo craters, a morphologic range from sharp-rimmed craters to shallow rimless depressions, and clusters of small craters which are probable farflung secondaries, and 8) a multitude of block fields and bedrock exposures exceeded in number only by those around and in the large young craters such as Aristarchus and Tycho.

Most of the aforementioned features have numerous well-known terrestrial analogs in areas of recent and current volcanic activity such as Hawaii, Iceland, and the San Francisco volcanic field in Arizona. As these lunar features are similar in form and scale to the terrestrial ones, proponents of lunar volcanism need not appeal to an unusual set of physical conditions to explain the photographic data. The features observed are familiar to experienced volcanologists when account is taken of the masking effect of random "impact noise." Examples of some of these terrestrial volcanic features are shown in figures 1, 2, and 3.

SCIENTIFIC OBJECTIVES

The scientific objectives of a surface mission in this area are to gather geologic, petrographic, geophysical, and geochemical data that bear on the origin, history, and age of the Marius Hills. If the steep domes, punctured cones, and narrow ridges are composed of different types of volcanic rock that is more silicic than the rocks of the maria, magmatic differentiation must have occurred on the Moon, attesting to a long and complicated volcanic history for even this small planetary body. Geophysical data in context with the geology, petrology, and geochemistry, may contribute to establish the character of local upper-crustal fracture control and to test the convection hypothesis. An important by-product may be the discovery of concentrations of now crystallized volatile materials that were initially released beneath the insulating regolith.

To satisfy the scientific requirements the following operational objectives must be met: 1) several of each type of the major constructional features must be described and sampled in detail, and oblique surface photography must be obtained, 2) the origin of the punctured cones and associated features must be established by field description, photography, and sampling, 3) the exceptionally fresh narrow ridge in the southwest part of the exploration area (pl. 2) should be investigated with the view of establishing whether or not it is eruptive, 4) a local stratigraphic sequence should be established by direct observation of local superposition and intersection relations, and 5) in order to establish subsurface structure, geophysical measurements should be made over the longest possible base lines.

OPERATIONAL GUIDELINES

Surface Exploration Constraints

1. Vehicles available for manned scientific sorties:
   a) Lunar Roving Vehicle (LRV)
   b) Lunar Flying Unit (LFU)
2. Traverse limitations:
   a) Maximum operating radius from Extended Lunar Module (ELM) with LRV and LFU is 5 km
   b) Maximum operating radius from ELM on foot traverses is 1½ km
   c) One astronaut must be within 1½ km ("walk back") of ELM while the other is beyond this distance with LRV or LFU

Figure 1.--Linear pyroclastic cone typical of many of the volcanic vents in the San Francisco field, northeast of Flagstaff, Ariz. Length 1.6 km, width 0.95 km, height 150 meters. This cone compares closely in form to the feature sampled at F-II-2 (large-scale map).

Figure 2.--Multiple pyroclastic cone with well-developed internal septum, San Francisco field, northeast of Flagstaff, Ariz. Length 1.5 km, width 1.3 km, height 240 meters. This structure is similar in form and scale to the multiple cone in the southeast corner of the large-scale map.

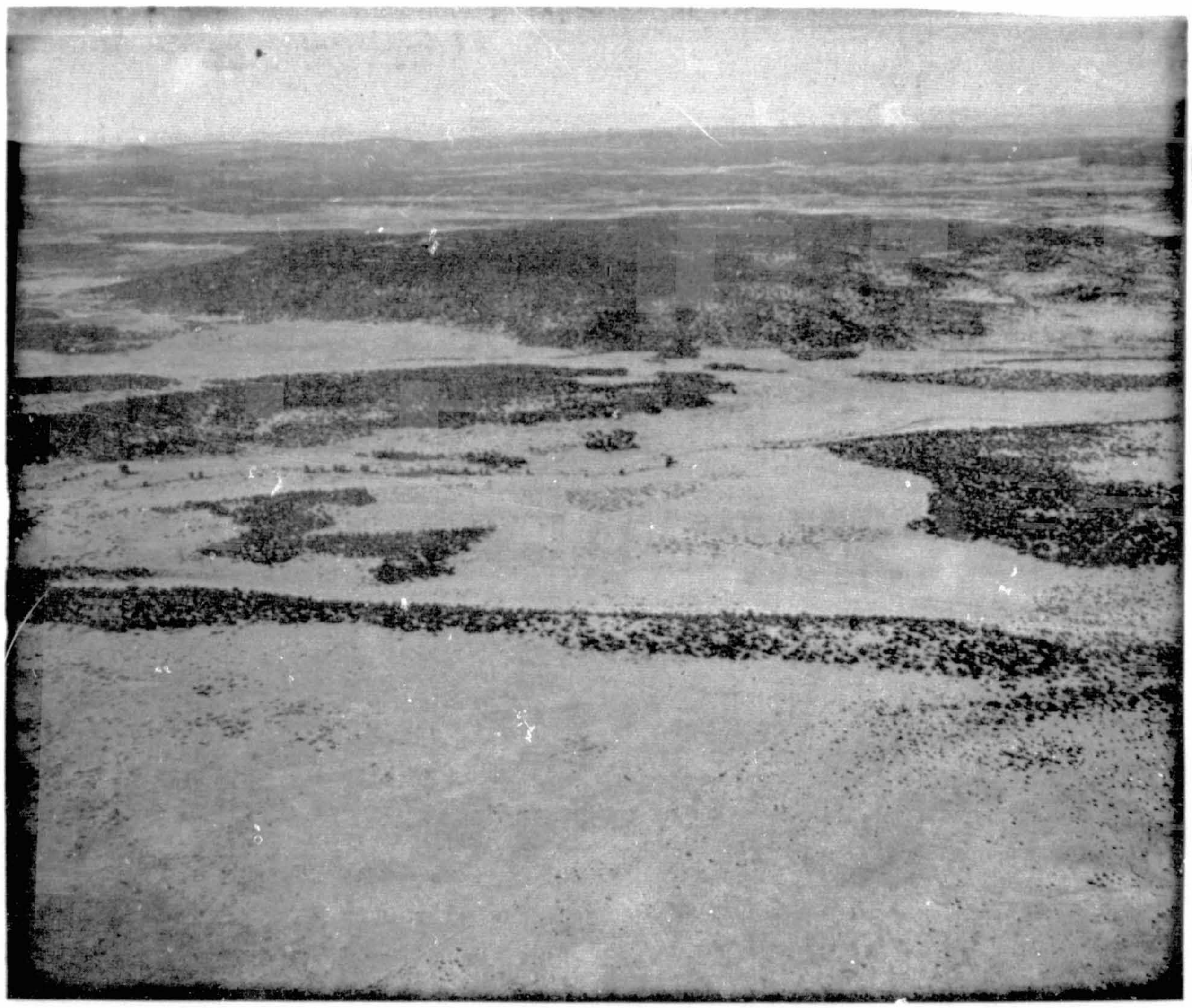

Figure 3.--Small shield volcano (Howard Mesa) in middle background, San Francisco field, northwest of Flagstaff, Ariz. Roughly circular in form, diameter 5 km, maximum height 150 meters. This structure, composed of intermediate andesite flows, is a possible analog of the steep domes.

d) LRV is capable of 4 traverses

e) LFU has sufficient fuel for at least 2 traverses (2nd LFU fully fueled and on standby basis for rescue operations)

3. Mobility unit speeds:

a) LRV - normally about 5 km per hr, which may include very quick stops for observation and sampling without dismounting. Up to 10 km per hr in especially favorable terrain

b) LFU - sufficiently fast that traverse time is negligible

4. Extravehicular Activity (EVA) times:

a) Total EVA time is 24 man-hours; limited to 4 EVA's of 3 hours each

b) Both astronauts must be outside during each EVA

5. Mobility unit science payload (excluding one astronaut):

a) LRV - 400 lb round trip

b) LFU - 180 to 240 lb round trip, depending on total distance of the two-stop traverses

6. Assumptions:

a) Navigation equipment on LRV and communication and telemetry equipment on the LRV and LFU are not a part of the science payload on mobility units

b) Payload capability of LRV can be "stretched" on first traverse to approximately 450 lb for first 600 meters to allow carrying ALSEP and other equipment to ALSEP deployment area

c) Operational procedures and equipment design will be such that 15 minutes is sufficiently long at the end of the LRV traverses for unloading samples and preparing the vehicle for the following EVA

d) It is assumed, for the purposes of this report, that lighting and sun angle are not limiting factors

Launch Vehicle Payloads Charged to Science

Saturn V (1,000 lb capability)		Payload (lb)
1.	Stay time extension	250-500
2.	Two LFU's (one for traverses, one for rescue)	360
3.	Two LFU Navigation units	50
4.	Geologic tools for LFU	15
5.	Contingency Portable Life Support System (PLSS)	120
6.	Two communications relays	10-20
7.	Lunar Surveying System (LSS)--for LFU	70
8.	Sample return containers (2)	40
		915 lb

Titan III C (2,800 lb capability)		
1.	LRV (including navigation equipment)	600
2.	LSS (for LRV)	70
3.	Geologic tools (including extra sample bags and drive tubes)	30
4.	ALSEP (mounted on LRV)	300
5.	Two 3-geophone seismic arrays	20
6.	One 8-geophone seismic array	10
7.	Titan-mounted drill	50
8.	Heat-flow probes	10
9.	Explosives (13 LRV, 3 LFU)	80
10.	Magnetometer (mounted on LRV, including boom)	25
11.	Magnetometer (for LFU)	10
12.	Two gravimeters	20
13.	Off-loading equipment for LRV	100
14.	X-ray diffractometer - αK_{α} spectrometer	35
15.	Sample-preparation equipment	20
16.	Worktable for analytical equipment	10
		1,390 lb

Scientific Mission Support

It is assumed in this mission plan that a scientific data facility is operating during the mission at Mission Control Center, Houston. Telemetered data from the X-ray diffractometer - αK_{α} spectrometer, magnetometer, and gravimeter are analyzed in near-real time. Teams of scientists and technicians monitor the astronauts' descriptions and the television images from the lunar surveying systems,[1/] encode the map data, and compile, correlate, and synthesize the stratigraphic, petrographic, structural, and analytical data. Pertinent results from the analysed and compiled data are then provided the astronauts upon request, along with consultation on other geological or geophysical problems. Many routine duties, such as telling the astronauts which sample numbers pertain to a given map unit so that they can select a specific sample for petrological analysis, will also be performed at the scientific data center.

The Active Seismic Experiment explosives will be detonated from this facility after the mission.

EVA ACTIVITIES AND PRELIMINARY TIME LINES

The EVA activities of the proposed preliminary lunar exploration plan are summarized in table 1. The proposed traverses,

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[1/] Careful consideration indicates the need for a Lunar Surveying System (LSS) on both the LRV and LFU. The payload capabilities of the launch vehicles and those of the LRV and LFU are sufficient for the two systems.

The LSS would enable detailed study of an area (or station) to be conducted rapidly and therefore should be used in the detailed exploration planned for the LFU stations. On the other hand, the time available for geologic exploration at the LRV stations is limited, and use of an LSS would ensure the return of at least a moderate amount of detailed information.

The present S-band system probably could not accommodate the simultaneous use of two LSS's. However, both LSS's could be effectively used by "time sharing": the astronaut with the LFU uses his LSS when the other astronaut is driving the LRV. This "sharing" of the S-band system could be coordinated by means of voice communication.

Table 1.--Summary of EVA activities--Lunar exploration plan for Marius Hills region of the Moon

	DAY I	DAY II	DAY III
MORNING	LANDING	EVA II (3 hr) 1st astronaut: Foot traverse around ELM; geologic observations and sampling; sample analysis. Drill hole and emplace probes for heat-flow experiment. 2d astronaut: 6.8 km LRV traverse, 1 hr 20 min driving time, 1 hr 40 min station stops and unloading. Sample return capability 145 lb.	EVA IV (3 hr) 1st astronaut: Activity around ELM--preparation and selection of samples for return to earth. 2d astronaut: 6.3 km LRV traverse 1 hr 10 min driving time, 1 hr 50 min station stops and unloading. Sample return capability 160 lb.
AFTERNOON	EVA I (3 hr) 1st astronaut: Inspection of ELM, extension of equipment, testing of LFU's (1 hr). LFU traverse (2 hr). Two stops, 9.2 km total distance. Science load--240 lb. Sample return capability 95 lb. 2d astronaut: Check out LRV and deploy ALSEP (1 hr); continue LRV traverse of 3.1 km: 40 min driving time, 1 hr 20 min stops. Sample return capability 275 lb.	EVA III (3 hr) 1st astronaut: 10.1 km LFU traverse: two stops, science payload 180 lb. Sample return capability 50 lb. 2d astronaut: 5.6 km LRV traverse: 1 hr 15 min driving time. 1 hr 45 min station stops and unloading. Sample return capability 155 lb.	Total potential sample return: LFU 145 lb LRV 735 lb Total potential to ELM 880 lb TAKEOFF

designed to return the optimal amount of geologic and geophysical data, are shown on plate 2. More detailed descriptions of EVA and traverse activities with estimated time lines follow.

The driving times given are crude estimates to the nearest 5 minutes using an average velocity of 5 km per hr and considering gross variations in surface roughness that would affect ground speed. More precise estimates would require 1) the preparation of detailed surface roughness maps, and 2) better figures on operational characteristics of the LRV in crossing different types of lunar terrain. Research on these lunar trafficability problems is presently underway by the U.S. Geological Survey (Ulrich, 1968).

DAY I EVA I

	Driving time	Station time	Elapsed time
Astronaut 1			
(a) Inspect ELM, deploy equipment, unload and test LFU.			1 hr
(b) Conduct LFU-I traverse. Total distance 9.2 km, two stops, 240 lb payload.			
Station 1--on rim of punctured cone (pc): geomorphic form of this and other punctured cones in the site suggests cinder cones composed of mafic (possibly basaltic) rocks. Distance 2.3 km.		45 min	1 hr, 45 min
(a) Detailed geologic observations, picture taking, and sampling of rim materials, particular attention directed to the bedrock or			

	Driving time	Station time	Elapsed time
blocky materials and to interior structures of the cone. Sample suite should be collected so that it can be used, insofar as possible, as a type-example representative of cones of this type. Sample should be large enough for a portion to be analyzed at the ELM; samples should be related to their local geologic environment through description, the LSS tracker, and imaging systems. If cone is volcanic, atypical fragments (possible xenoliths from depth) should be sought.			
(b) Deploy communications repeater.			
(c) Deploy ASE explosives.			
Station 2--on contact between plateau plains (pp) and narrow ridge unit (nr), and near large plateau plains crater that may have ejected blocky bedrock material that underlies the plains surface. Distance 2.55 km.		45 min	2 hr, 30 min

	Driving time	Station time	Elapsed time
(a) Detailed geologic observations, photograph narrow ridge structure (nr) (the form of which suggests a viscous siliceous extrusion from a fissure vent) and the contact zone between the narrow ridge (nr) and plateau plains (pp). Samples, especially from the ridge structure, should be taken bearing in mind the requirements discussed for sampling at station 1.			
(b) Deploy 3-geophone ASE array.			
Return to LEM--distance 4.35 km--unload samples and refuel LFU.		30 min	3 hr
<u>Astronaut 2</u>			
(a) Retrieve unloaded LRV and deploy ALSEP approximately 600 meters from ELM, taking representative samples and photographs at instrument sites.			1 hr
(b) Conduct LRV-I traverse; 3.1 km long, 40 min driving, 1 hr and 20 min station time.			

	Driving time	Station time	Elapsed time
Geologic observations, picture taking, and sampling of craters, surface materials, and structures, to provide a representative sample of the plateau plains unit for comparison with mare samples obtained on previous missions.			
Station 1--relatively smooth area of plains; distance 0.3 km.	5 min	20 min	1 hr, 25 min
(a) Observe and sample small craters, surface materials, textures, shallow stratigraphy, and surface alteration features. Attempt to establish origin of craters by studying and documenting morphology, structure, stratigraphy, and lithologic characteristics.			
(b) Deploy ASE explosives.			
Station 2--on rim of large crater surrounded by blocky ejecta; probably either a modified impact crater or a volcanic caldera. Distance 1.2 km.	15 min	20 min	2 hr
(a) Sample rim materials, observe and photograph interior structures of crater. Look for evidence of stratigraphic			

	Driving time	Station time	Elapsed time
units (either exposures in walls or variations in blocky material). If layering exists, collect representative samples from exposed layers and from different blocks. Relate samples to local geologic environment through description, imagery devices, and LSS tracking.			
(b) Deploy ASE explosives.			
Station 3--in smooth plains area with fine structures that may represent a young surficial deposit. Distance 0.8 km.	10 min	20 min	2 hr, 30 min
(a) Observe and sample surface materials and structures; attempt to establish relations of materials to fine structures.			
(b) Deploy ASE explosives.			
ELM--unload LRV and plug into ELM for battery recharge. Distance 0.8 km.	10 min	20 min	3 hr

Payload for LRV-I traverse:

		Weight (lb)
1.	ALSEP	300
2.	Lunar Surveying System	70

	Weight (lb)
3. Geologic tools (pick, scoop, hand lens, tongs, sample bags, drive tubes, carrier)	20
4. Gravimeter (automatic recording)	10
5. Magnetometer (automatic recording)	25
6. Seismic charges (3)	15
	440
Sample return capability after deployment of ALSEP and ASE equipment	275
Payload for LFU-I traverse:	
1. Lunar Surveying System (LSS)	70
2. Geologic tools (pick, scoop, tongs, sample bags, hand lens, map, carrier, drive tubes)	15
3. Long seismic array (3 geophones)	10
4. Gravimeter	10
5. Magnetometer	10
6. Seismic charges (1)	5
7. Navigation equipment	25
8. Communications relay	5
	150
Sample return capability after deployment of ASE equipment and communications repeater	95

DAY II EVA II

	Driving time	Station time	Elapsed time
Astronaut 1			
Conduct LRV-II traverse; 6.8 km			

	Driving time	Station time	Elapsed time
long, 1 hr 20 min driving time, 1 hr 40 min station time.			
Station 1--contact between plateau plains (pp) and low dome (ld) units. Two large craters on either side of contact should provide samples of bedrock if the map units are obscured by thick mantling deposits.			
Distance 1.4 km.	15 min	20 min	35 min
(a) Geologic observations, picture taking, sampling of surface materials of both units. Collect as many different lithologic types as possible from each unit. If contact is locally exposed, note whether it is structural, intrusive, or depositional in character, and describe the structure and apparent relative ages of the juxtaposed bedrock.			
(b) Deploy ASE explosives.			
Station 2--contact between punctured cone (pc), low dome (ld), and steep dome (sd) materials.			
Distance 1.3 km	15 min	20 min	1 hr, 10 min

	Driving time	Station time	Elapsed time
(a) Geologic observations, picture taking, and sampling of materials from the three units. Note mineralogic similarities or differences in samples; compare with those taken previously. Particularly note contact and apparent age relations as suggested by morphologic relations. Is the low dome (ld) unit younger than the punctured cone (pc) unit?			
(b) Deploy ASE explosives.			
Station 3--contact between low dome (ld) and steep dome (sd) units.			
Distance 1.1 km.	15 min	20 min	1 hr, 45 min
(a) Geologic observations, picture taking, and sampling of material in contact zone. Collect talus material derived from upper slopes. Compare mineralogy with that of steep dome material sampled at station 2.			
(b) Deploy 3-geophone ASE array. On extended traverse, deploy ASE explosive instead.			
Station 4--on triple contact point between low dome (ld),			

	Driving time	Station time	Elapsed time
steep dome (sd), and bulbous dome (bd) materials.			
Distance 0.4 km.	5 min	20 min	2 hr, 10 min
(a) Geologic observations, picture taking, and sampling, particularly of the bulbous dome (bd) materials and of contact relations.			
(b) Deploy ASE explosives.			
At ELM--unload LRV and plug into ELM to recharge batteries.			
Distance 2.65 km	30 min	20 min	3 hr

Alternative traverse: If at station 2 it is decided that EVA time will permit an extended traverse, the traverse will proceed to the following stations:

Station 2A--near large crater on steep dome (sd) unit.

(a) Geologic observations, picture taking, and sampling of materials on the top of a steep dome structure. Blocky ejecta from crater should provide information on the character of bedrock beneath the surface. Carefully note small

	Driving time	Station time	Elapsed time
structures and collect samples for comparison with steep dome unit to be studied on last traverse.			
(b) Deploy ASE explosives.			
Station 2B--at base of steep scarp on contact between lo. dome (ld) and steep dome (sd) units. Character of scarp suggests bedrock locally exposed or near surface.			
(a) Geologic observations, picture taking, and sampling of materials in contact zone. Particularly note structure and stratigraphy that may be exposed in scarp. Collect samples of talus material derived from higher parts of the scarp. By comparison with previous samples, and reference to geologic map, attempt to determine which layers talus samples came from.			
(b) Deploy 3-geophone ASE array here, rather than at station 3. Deploy an ASE explosive at station 3.			

	Driving time	Station time	Elapsed time
Astronaut 2			
Conduct foot traverse and experiment about ELM.			
(a) Detailed geologic observations, picture taking, and sampling of different crater types and materials of the plateau-plains (pp) unit within a few tens of meters around ELM.		1 hr	1 hr
(b) Organize samples from previous traverses. Prepare at least one sample that appears most representative of punctured cone (pc), and at least one sample that appears most representative of ridge structure (nr); analyze samples on X-ray diffractometer-αK_{α} spectrometer. Comparison of these samples, which are possible end members of magmatic differentiation sequence, may aid in later field selection of samples on remaining traverses.			
(c) Set up and start drill for heat-flow probes.			
(d) If time permits, select most representative sample (possibly from blocky			

	Driving time	Station time	Elapsed time
material near crater rim, LRV-I, station 2) of relatively large crater in plateau plains (pp) unit, prepare, and analyze on X-ray diffractometer-αK_{α} spectrometer for comparison with first two samples.			
(e) Install heat-flow probes in drill hole.		2 hr	3 hr

Payload for LRV-II traverse:

		Weight (lb)
1.	Lunar Surveying System (LSS)	70
2.	Geologic tools (pick, scoop, hand lens, tongs, sample bags, drive tubes, carrier)	20
3.	Gravimeter (automatic recording)	10
4.	Magnetometer (automatic recording)	25
5.	Long seismic array (3 geophones)	10
6.	Seismic charges (5--including 2 extra for extended traverse)	25
7.	Contingency PLSS	120
		280

Sample return capability after deployment of ASE equipment	145

DAY II EVA III

	Driving time	Station time	Elapsed time
Astronaut 1			
Conduct LFU-II traverse; 10.1 km, 2 stops, ≅180 lb payload			
Station 1--on crest of punctured cone, in area of bedrock (spatter lava?) or bouldery material. Distance 5 km.		30 min	30 min
(a) Geologic observations, picture taking, and sampling of rim material with particular attention to layered structures and structurally controlled features. Compare any observable stratigraphy and lithologies to those observed on punctured cone west of ELM (LFU-I traverse, station 1); sample specifically with this comparison in mind. Document as completely as practical with imagery systems any stratigraphy and structures for comparison with possible terrestrial analogs.			
(b) Deploy ASE explosives.			
Station 2--on crest of elongate punctured compound cone (pc) with blocky material. Distance 1.2 km.		30 min	1 hr
(a) Geologic observations,			

	Driving time	Station time	Elapsed time
picture taking, and sampling of rim material with particular attention to surface structures that may explain the elongate form and origin. Note blocky-appearing material just west of station; if lighting is no problem, carefully scan opposite rim for bedrock exposures; compare with previously observed punctured cones.			
(b) Deploy communications repeater.			
(c) Deploy ASE explosive.			
Return to ELM--distance 3.9 km.		2 hr	3 hr
(a) Refuel LFU			
(b) Continue organization of samples; prepare and analyze at least one representative sample from each of the two cones for comparison with the analyzed previous day's samples of cone (pc) material and other material. If a sample can be selected that appears representative of the steep dome (sd) bedrock material from the LRV-II traverse, prepare			

	Driving time	Station time	Elapsed time
and analyze for comparison with punctured-cone and, especially, narrow-ridge materials.			
Astronaut 2			
Conduct LRV-III traverse; 5.6 km long, 1 hr 15 min driving time, 1 hr 45 min station time.			
Station 1--near rim of plateau plains crater.			
Distance 0.8 km.	10 min	15 min	25 min
(a) Detailed geologic observation, picture taking, and sampling of crater with particular attention to determining its age and origin and relation to nearby structural features and materials. Compare with larger crater observed on LRV-I traverse; study and collect any material that appears representative of bedrock for comparison with that from larger crater, to aid in determining origin of both craters.			
(b) Deploy ASE explosive.			
Station 2--on contact between plateau plains (pp) and steep dome (sd) materials.			

	Driving time	Station time	Elapsed time
This is the first station where plateau plains material may be observed in contact with steep-dome materials; subdued but relatively large crater just east of station may have ejecta blocks representative of both steep dome and plateau plains bedrock material.			
Distance 0.5 km.	5 min	15 min	45 min
(a) Detailed geologic observation, picture taking, and sampling of contact zone to work out age and contact relations.			
Station 3--on contact between steep dome (sd) and punctured dome (pd) materials.			
Distance 0.3 km.	5 min	15 min	1 hr, 5 min
(a) Geologic observations, picture taking, and sampling of the two units with special attention to contact and age relations and lithologies and textures of the two units. Make brief comparison between this punctured cone and those studied on LFU traverses.			

	Driving time	Station time	Elapsed time
Astronaut 2 remains at this station, or within the 1.5-km walkback radius, until astronaut 1 returns to the ELM from his flying traverse.			
Station 4--small rille in the marginal zone of the plateau plains (pp) unit. Distance 1.2 km.	15 min	20 min	1 hr, 40 min

(a) Geologic observations, picture taking, and sampling of rille materials, paying particular attention to structural features and stratigraphy in the floor and walls of the rille. (Rille structure may be largely, if not completely, obscured by mantling material--astronaut must watch closely for any hint of exposed rille structures.)

(b) Deploy 8-geophones array across rille axis.

(c) Deploy ASE explosive.

(d) Driving between stations 4, 5, 6, astronaut should be especially alert for atypical material that may be xenoliths if cone is volcanic.

	Driving time	Station time	Elapsed time
Station 5--on shoulder between two pierced cones. The flank of one cone apparently overlaps that of the other. Distance 0.5 km.	10 min	10 min	2 hr
(a) Geologic observations, picture taking, and sampling along the contact zone to determine lithologic differences and age relations and for comparison with previously sampled cones.			
Station 6--on contact between plateau plains (pp) and steep dome (sd) units. Distance 0.5 km.	10 min	10 min	2 hr, 20 min
(a) Geologic observations same as at station 3.			
(b) Deploy ASE explosive.			
Return to ELM, unload samples, and plug LRU into battery charger. Distance 1.9 km.	20 min	20 min	3 hr

Payload for LRV-III traverse:	Weight (lb)
1. Lunar Surveying System (LSS)	70
2. Geologic tools (pick, scoop, hand lens, tongs, sample bags, drive tubes, carrier)	20
3. Gravimeter (automatic recording)	10
4. Magnetometer (automatic recording)	25
5. Short seismic array (8 geophones)	10

		Weight (lb)
6.	Seismic charges (3)	15
7.	Contingency PLSS	120
		270
	Sample return capability after deployment of ASE equipment	155

Payload for LFU-II traverse:

1.	Lunar Surveying System (LSS)	70
2.	Geologic tools (pick, scoop, tongs, sample bags, hand lens, map, carrier, drive tubes)	15
3.	Gravimeter	10
4.	Magnetometer	10
5.	Seismic charges (2)	10
6.	Navigation equipment	25
7.	Communications repeater	5
		145
	Sample return capability after deployment of ASE explosives and communications repeater	50

	Driving time	Station time	Elapsed time

DAY III EVA IV

Astronaut 1

Sample preparation, analytics, and last sampling observations near ELM.

(a) The analytics consist of final sample sorting and

	Driving time	Station time	Elapsed time
selection for return to Earth. Communications with astronaut 2 on LRV traverse should determine how much allowance should be made for samples that are to be returned to Earth from this last traverse.			
(b) May conduct short flying sorties with the fueled safety LFU or the other LFU and remaining fuel. Final field observations and sampling of what have been determined to be the most critical plateau plains features within 1.5 km of ELM; one important feature may be the bright-rayed crater 1.5 km north of the ELM. These sorties can commence only after astronaut 2 on the LRV traverse returns to within 1.5 km of the ELM.			
Astronaut 2			
Conduct LRV-IV traverse; 6.3 km long, 1 hr 10 min driving time, 1 hr 50 min station time.			
Station 1--contact between plateau plains (pp) and low dome (ld) units.			
Distance 1.9 km.	20 min	15 min	35 min

	Driving time	Station time	Elapsed time
(a) Geologic observations, picture taking, and sampling, particularly comparing relations of surface materials and contacts with those previously examined at pp-ld contact zones.			
(b) Deploy ASE explosives.			
Station 2--contact between plateau plains (pp) and low dome (ld) units near a large plateau plains crater. Distance 0.8 km.	10 min	20 min	1 hr, 5 min
(a) Geologic observations, picture taking, and sampling of units along contact zone. Concentrate on collecting ejecta blocks from nearby plateau plains crater and talus material of slopes of low dome unit.			
(b) Deploy ASE explosives.			
(c) While traveling from station 2 to 3 and 4, especially on alternate route through stations 2a, 2b, 2c, astronaut be alert for bedrock exposures or blocks representative of bedrock materials; topography and textures suggest that bedrock and blocks may both			

	Driving time	Station time	Elapsed time
be present along this route.			
Station 3--triple contact point between low dome (ld), bulbous dome (bd), and steep dome (sd) materials. Distance 0.9 km.	10 min	25 min	1 hr, 40 min
(a) Geologic observations, picture taking, and sampling of units along contact zone. Devote special attention to materials and structures representative of the bulbous dome and compare with surrounding materials and materials of the punctured cones and narrow ridge. If time and topography permit, and if no bedrock exposures are present at station 3, astronaut should attempt brief stop at "bedrock" approximately 200 meters southwest of station.			
Station 4--triple contact point between plateau plains (pp), low dome (ld), and bulbous dome (bd) materials. Distance 0.9 km.	10 min	20 min	2 hr, 10 min

	Driving time	Station time	Elapsed time
(a) Geologic observations, picture taking, and sampling of units along contact zone. If materials representative of bulbous dome (bd) units have not been adequately sampled yet, astronaut should attempt a brief stop where relatively large crater intersects bulbous dome approximately 150 meters northeast of station.			
Return to ELM, unload samples and assist astronaut 1 in loading samples in ELM and preparing for takeoff.			
Distance 1.8 km.	20 min	30 min	3 hr
Alternate traverse: If at station 2 it is decided that a longer traverse is possible, proceed to the following stations, stopping at one or more if new information can be obtained from the stops.			
Station 2a--triple contact point between plateau plains (pp), low dome (ld), and bulbous dome (bd) materials.			
(a) Geologic observations,			

	Driving time	Station time	Elapsed time
picture taking, and sampling of units along the contact zones.			
Station 2b--top of steep dome (sd) unit and near what appear to be bedrock exposures.			
(a) Geologic observations, picture taking, and sampling with special attention to collecting bedrock or blocky material and noting possible internal structures and stratigraphy, and relation of "bedrock" to overlying mantling materials.			
Station 2c--triple contact point between steep dome (sd) and low dome (ld) units.			
(a) Geologic observations and sampling same as at station 3.			

Payload for LRV-IV traverse:	Weight (lb)
1. Lunar Surveying System (LSS)	70
2. Geologic tools (pick, scoop, hand lens, tongs, sample bags, drive tubes, carrier)	20
3. Gravimeter (automatic reading)	10
4. Magnetometer (automatic reading)	25

		Weight (lb)
5.	Short seismic array (8 geophones)	10
6.	Seismic charges (2)	10
7.	Contingency PLSS	120
		265
Sample return capability		160

BRIEF SUMMARY AND EVALUATION OF MISSION

1. Within the framework of the assumed operational contraints, the Lunar Exploration Plan meets minimum scientific objectives in providing for fairly comprehensive sampling of the major stratigraphic units in the Marius Hills (table 2) and the acquisition of several types of supporting geophysical data. The combined geologic and geophysical data should enable a detailed reconstruction of the geologic history of the area. This in turn will enable evaluation of current hypotheses regarding the origin and development of the Marius Hills.

2. The Lunar Flying Units and the Lunar Roving Vehicle are sufficiently versatile that traverses planned for areas of varied topography and geology will be highly flexible. The LFU provides rapid access to points of particular scientific importance that are difficult or impossible to reach by the slower, wheeled vehicle. On the other hand, the LRV permits more comprehensive coverage for ground observation and sampling, is more versatile in that minor alterations of the planned traverses can be readily made as the traverse develops, and is capable of carrying a larger payload. To provide adequate areal coverage by the LRV during a 3-day mission, stop-time at carefully selected sampling points must be held to a minimum, emphasizing the ever-present requirement that the total lunar exploration system be as automated and efficient as possible.

Table 2.--Sample density of materials from geologic units obtained by the proposed LRV and LFU traverses in the Marius Hills region

Traverses	Number of stations where the following geologic units will be sampled--					
	pc	sd	ld	bd	pp	nr
LFU-I	1				1	1
LFU-II	2					
Total LFU	3				1	1
LRV-I					3	
LRV-II	1	2	4	1	1	
LRV-III	3	3			4	
LRV-IV		1	4	2	3	
Total LRV	4	6	8	3	11	
Total LRV + LFU	7	6	8	3	12	1

3. As part of this total exploration system, the Lunar Surveying System, X-ray diffractometer- αK_{α} spectrometer, gravimeter, and magnetometer furnish data that can be used both for guiding the course of the mission and for providing information that is critical to the final geologic interpretations of the area.

The lunar Surveying System provides the means for rapidly locating observation and sample points and placing observations in the proper geologic context, and it supplies television images and tracking data required for proper monitoring of mission progress in Mission Control.

The X-ray diffractometer-αK_{α} spectrometer furnished mineralogic and chemical information to the astronauts that will direct selection of samples in the field and final selection of samples for return to Earth, and it will provide important information on samples that cannot be returned because of the sample-return load restriction (presently 80 lb). As illustrated by the mission described here, many more samples can be collected in the field and returned to the ELM than can be returned for study on Earth.

The gravimeter and magnetometer will enable detection of subsurface geophysical anomalies, thereby alerting the astronauts to possible expressions of these anomalies at the surface and aiding them in their on-the-spot interpretations. Although the active seismic experiment could be accomplished during manned exploration, present thinking suggests that detonation of the explosives from Earth after completion of the surface mission may be preferable because it would save astronauts time and would eliminate the necessity for transporting part of the detonating equipment to the Moon.

4. Geologic objectives within the Marius Hills region require a comprehensive areal sampling of surface features and deposits and of related subsurface information. Although the present mission plan provides sufficient areal coverage to satisfy many major scientific objectives, numerous critical features cannot be reached within the 5-km operating range because of serious time restrictions. A much more comprehensive geologic mission could be developed if stay time were extended and additional fuel were available for LFU traverses. Such capabilities are available within the assumed science payload of the Titan III-C. Additional major scientific objectives could be met by allotting 400 lb of the Titan III-C payload for 2 days extra stay time and 900 lb for fuel for three more LFU traverses. A Lunar Exploration Plan for a 5-day mission in the Marius Hills region is presently being prepared by the U.S. Geological Survey.

ADDITIONAL WORK REQUIRED

Because of the time limitations imposed on this effort, much additional study in basic and applied lunar geology will be required before a manned landing can be made in the area. This work includes: 1) A thorough theoretical study of the problem of lunar magmatic differentiation starting from the now justified assumption that the maria consist of primitive basalts, 2) Additional detailed regional and large-scale geologic study of the available photography and the preparation of a detailed geologic report on the area, 3) more thorough study of the terrestrial volcanic features that are believed to be analogs of those within the Marius Hills (of particular importance are the differentiated trachyte domes and cones in the Hawaiian Islands), 4) field simulation of the proposed surface traverses in the S. P. quadrangle near Flagstaff, Ariz., which contains a host of very similar geomorphic features, and 5) field training of the flight crews in the detailed geology of as many terrestrial analog features as time permits.

The use of properly designed maps is indispensible for a well-planned surface exploration mission. Maps of different scales and designed for specific scientific and operational purposes must be prepared for pre-mission planning of traverses, for use by the astronauts in locating the ELM and traverse station points during the mission, and for plotting transmitted scientific information in Mission Control. Continuing research is therefore required to determine optimal map scales and the nature and density of geologic, engineering, soils, and topographic notations to be added to the photographic base maps used during each Apollo mission.

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GEOLOGICAL SURVEY

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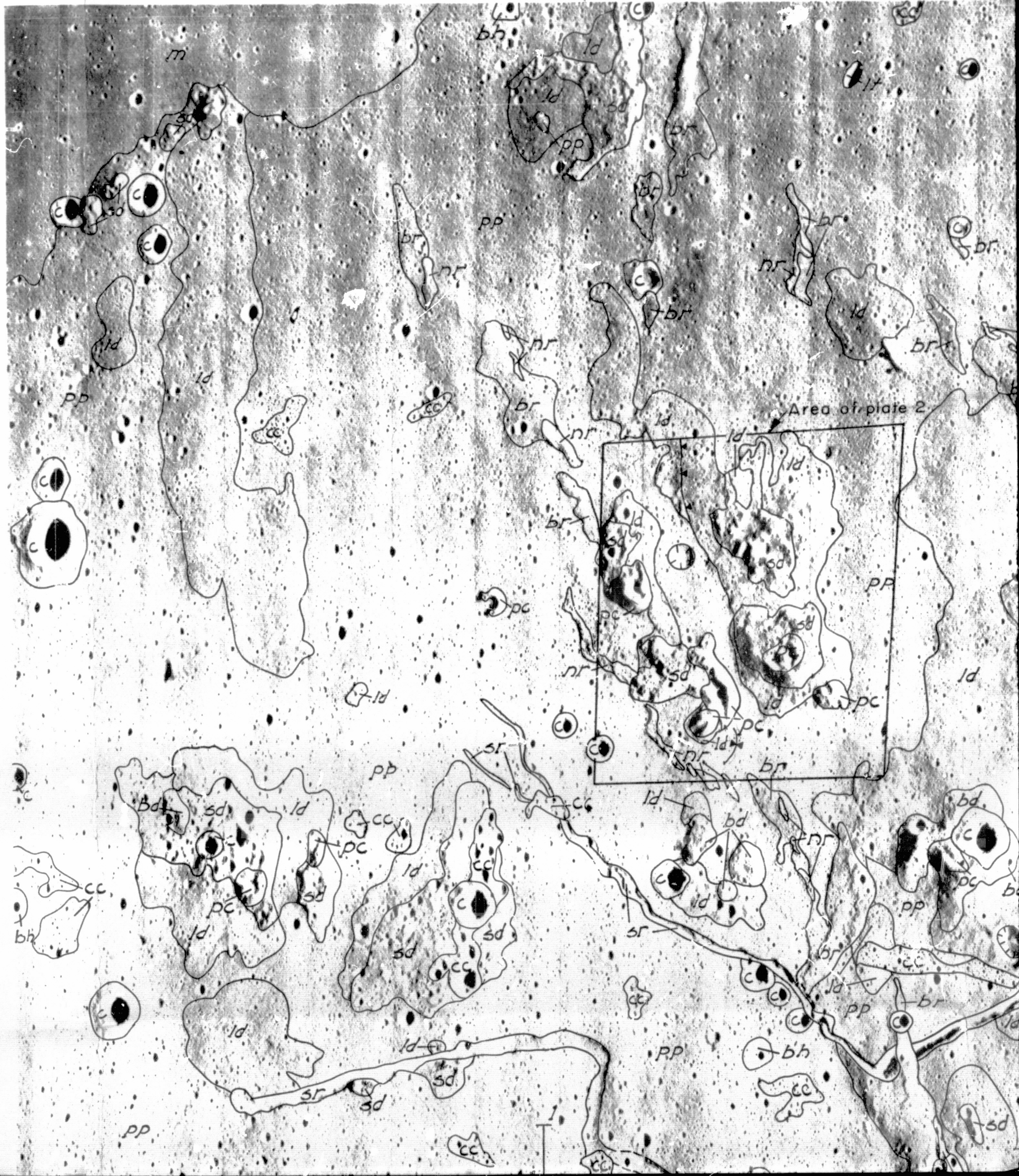

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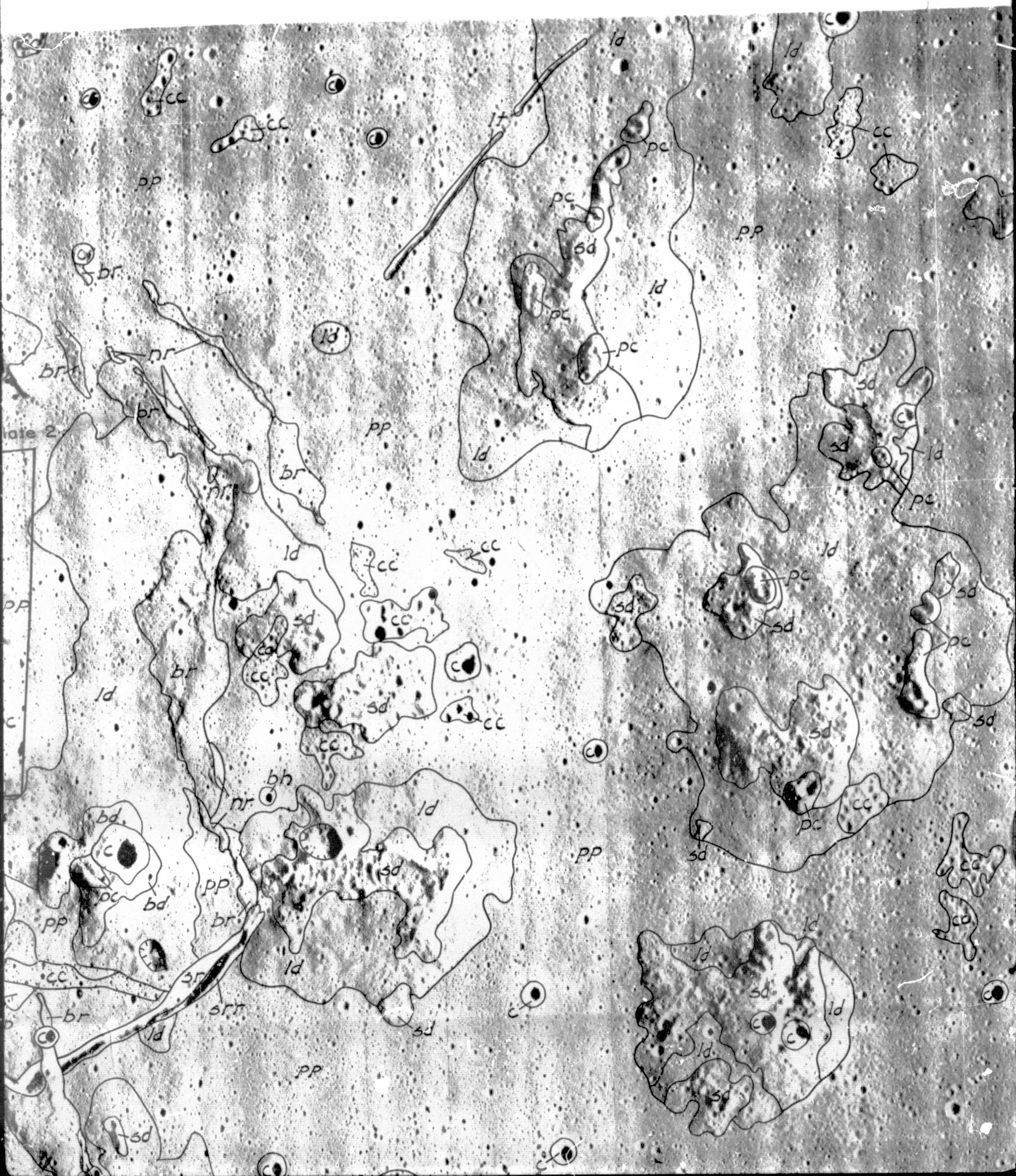
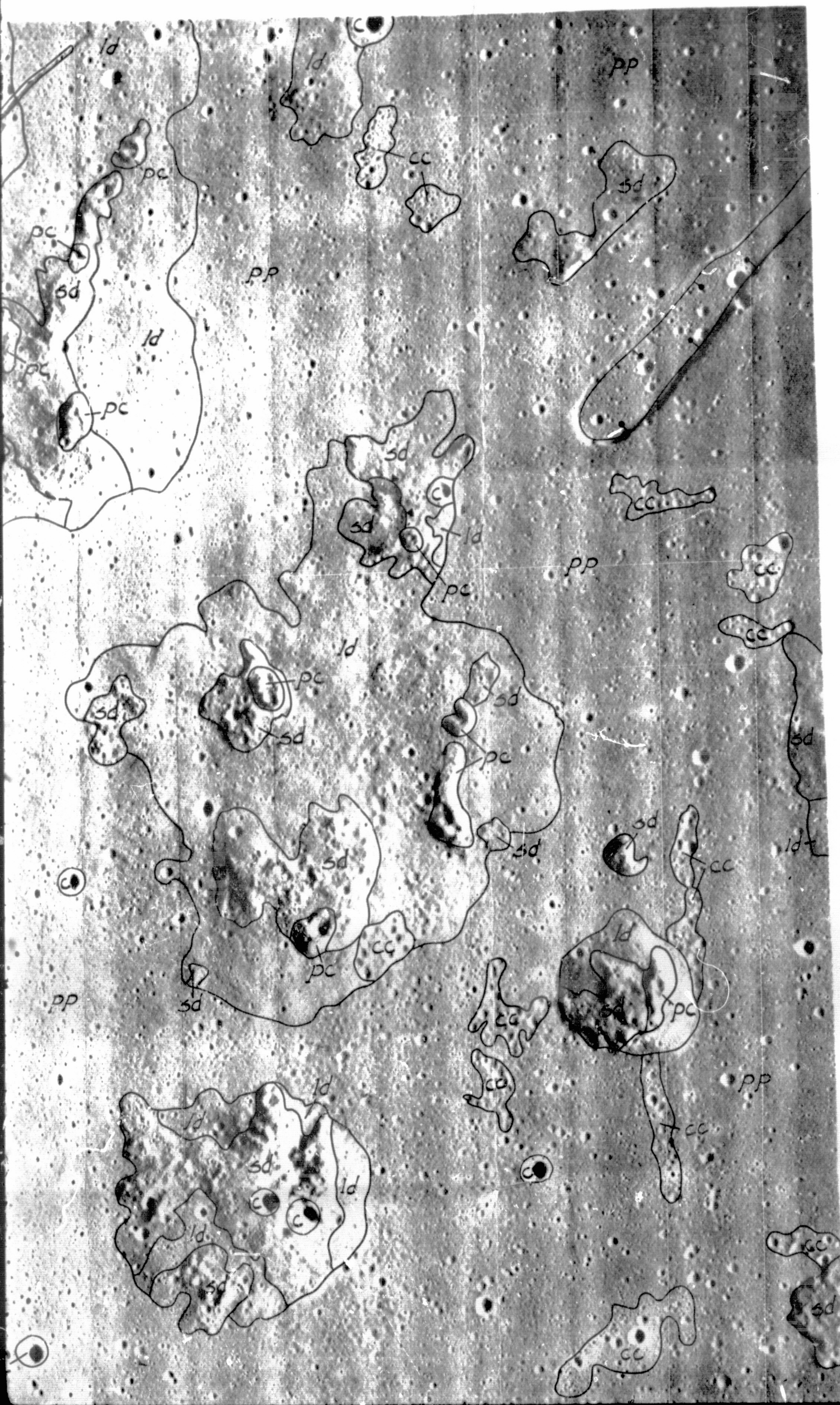


PLATE 1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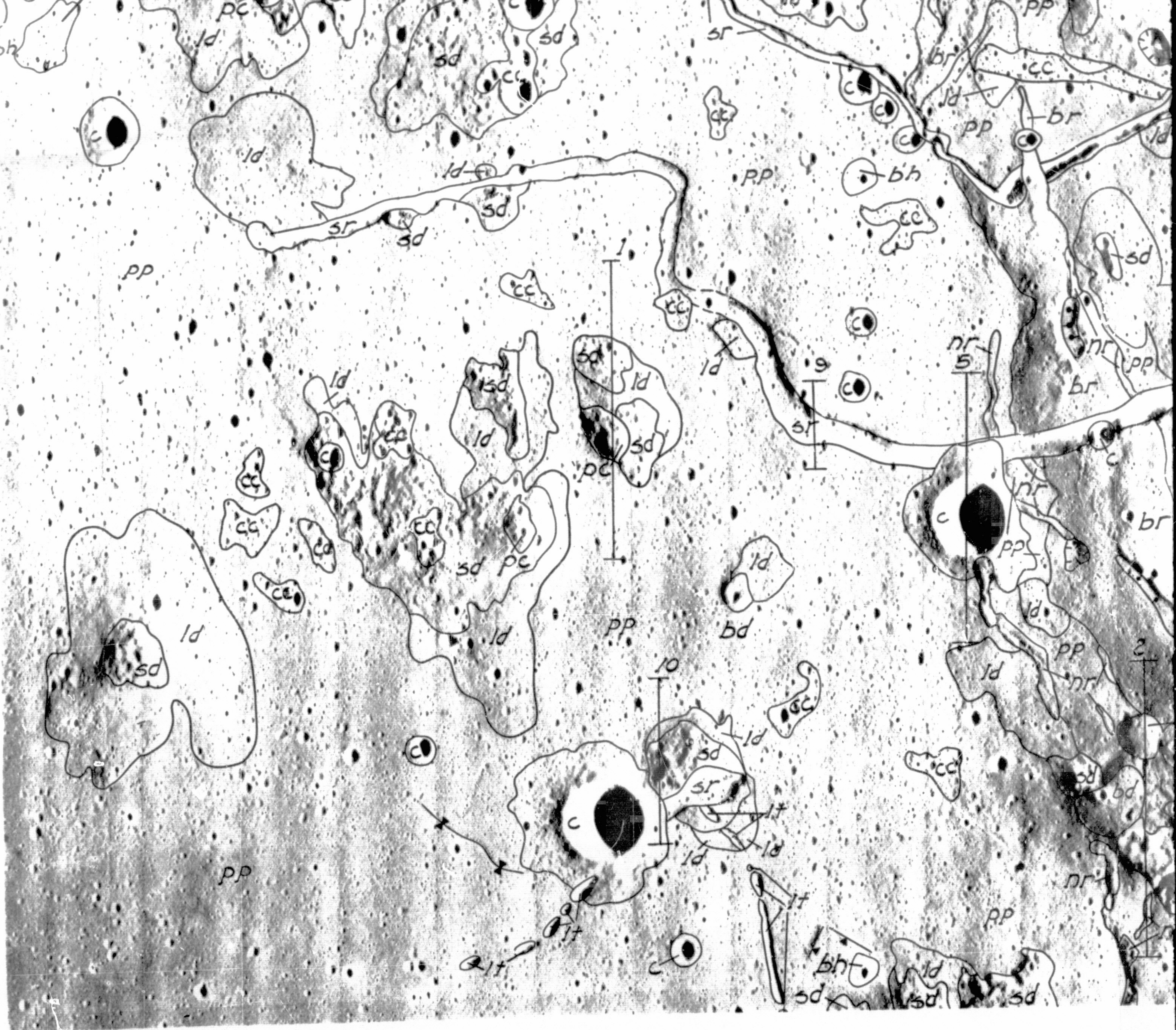

Photobase from Langley Research Center
uncontrolled photomosaic

PRELIMINARY SMALL-SCALE GEOLO

John

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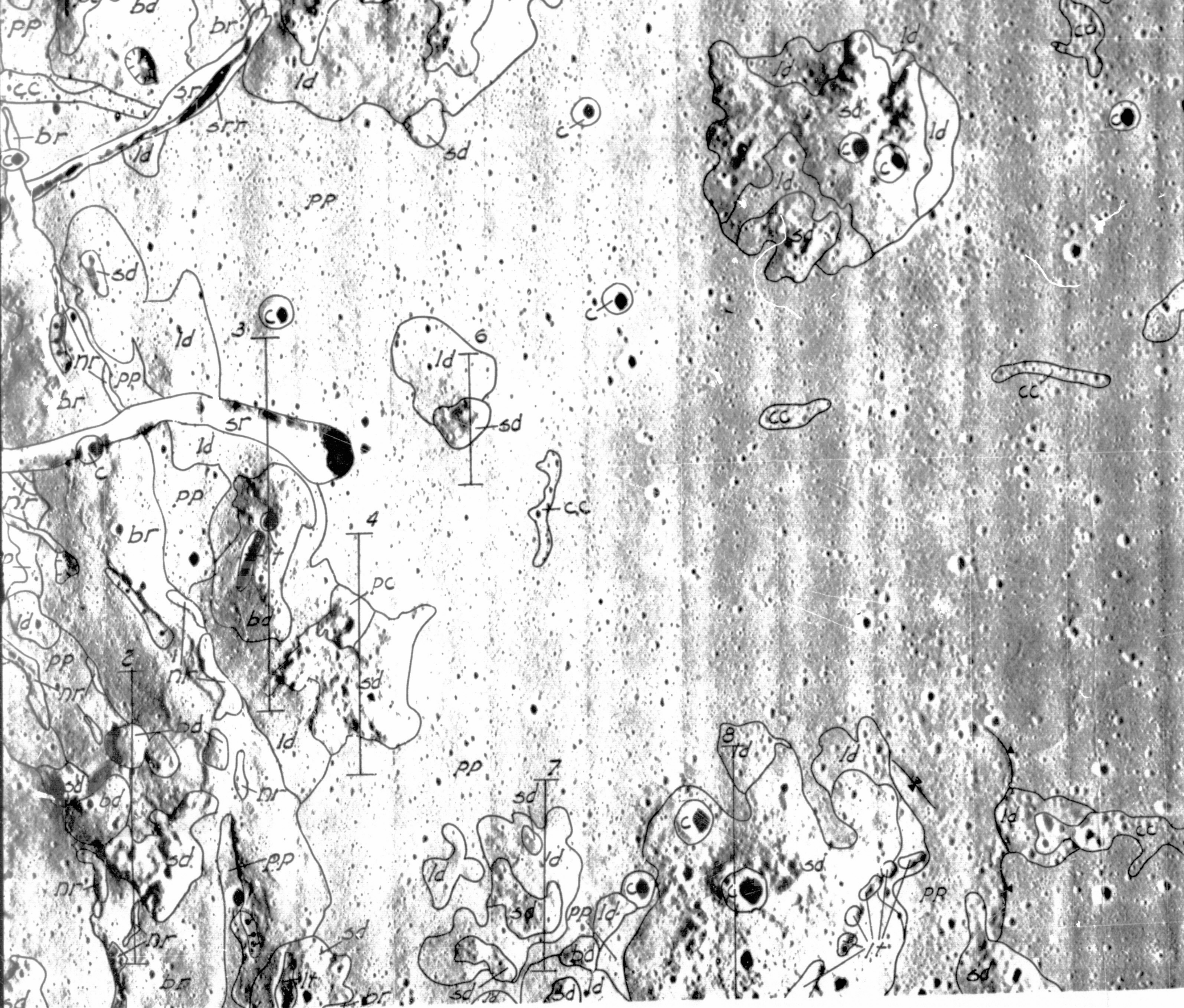
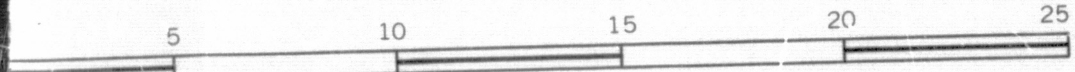


EOLOGIC MAP OF THE MARIUS HILLS RE

By
John F. McCauley

1968

APPROXIMATE SCALE 1:200,000



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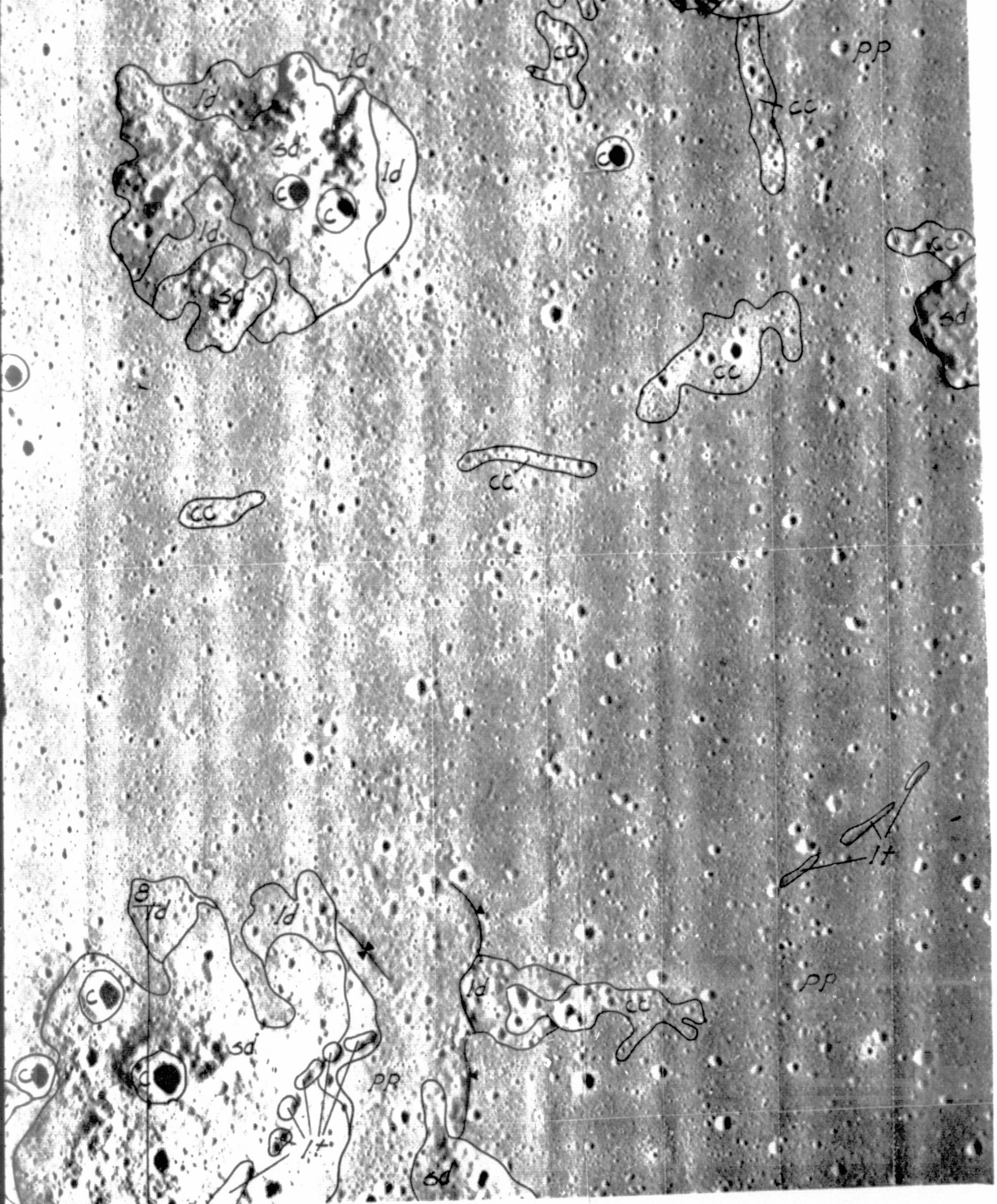

Geology mapped on Lunar Orbiter V photographs

E MARIUS HILLS REGION

5 KILOMETERS

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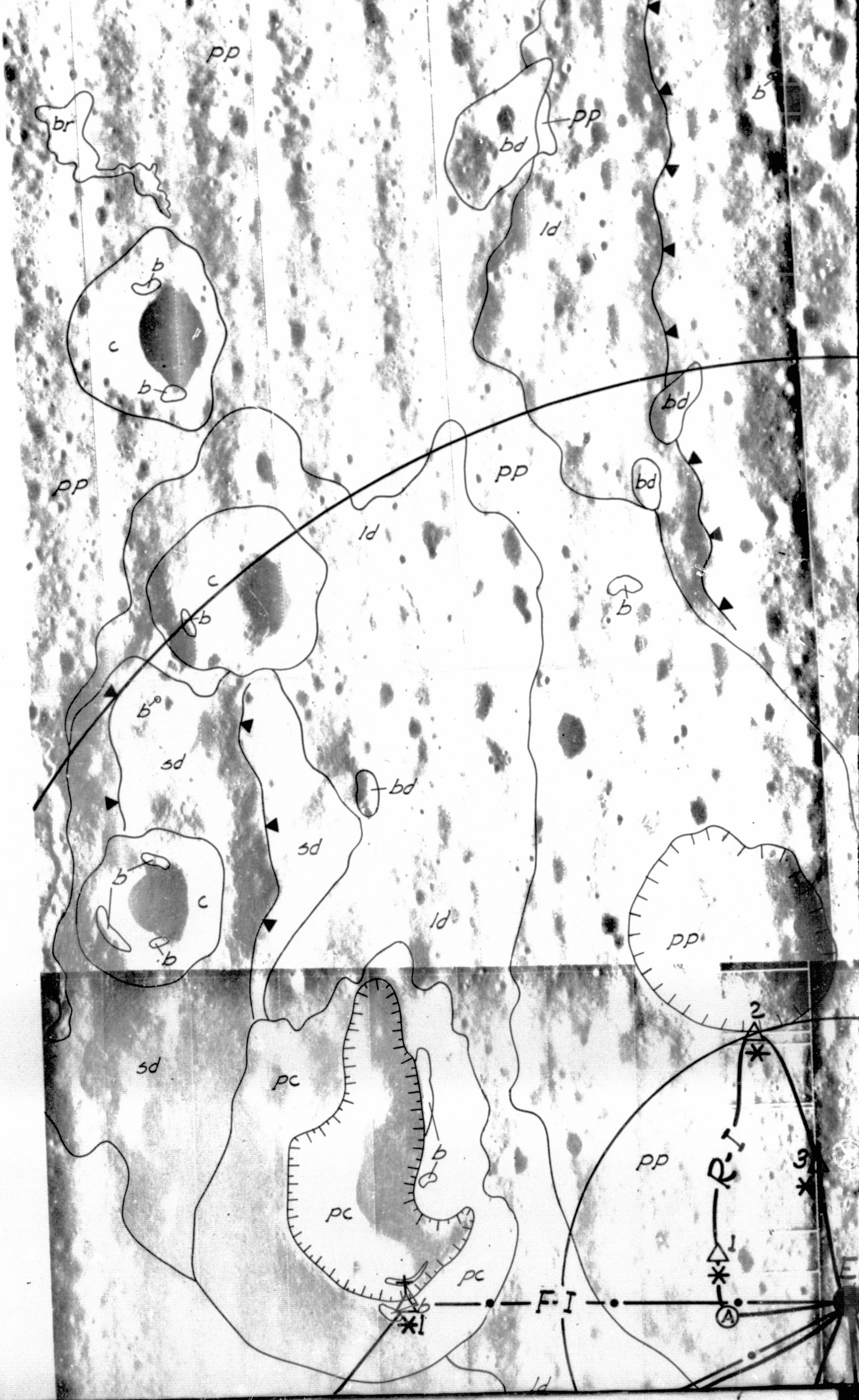
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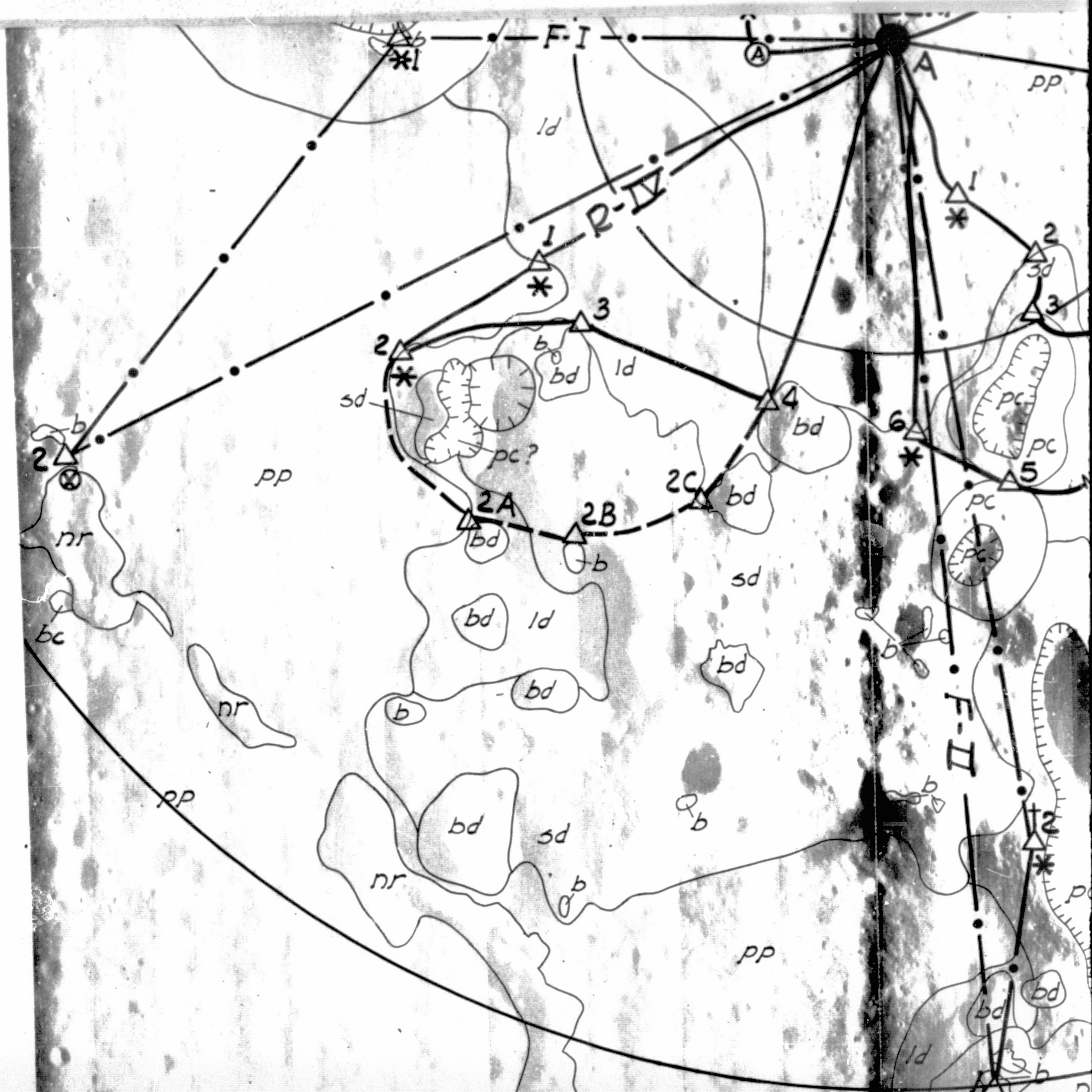

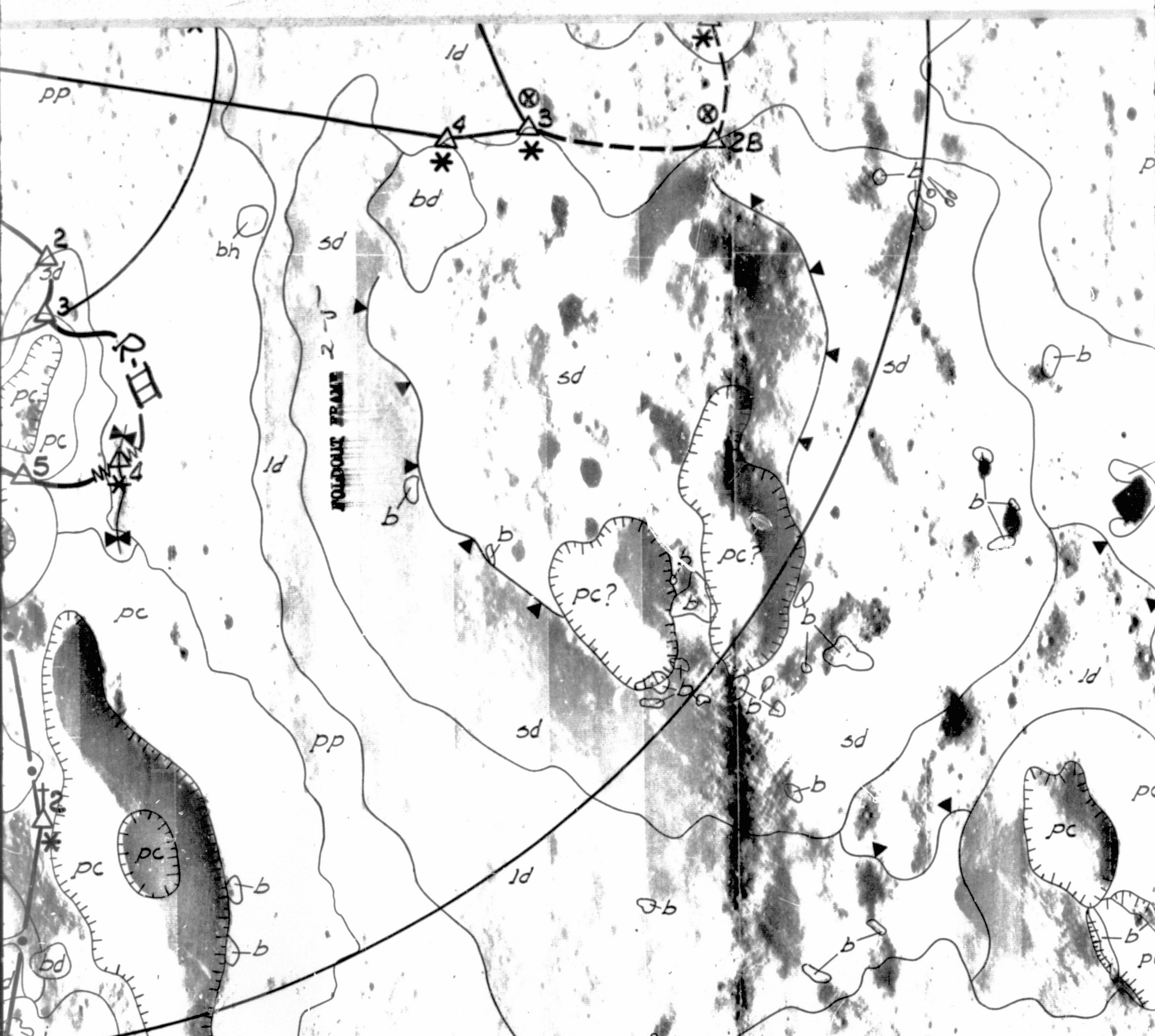

FOLDOUT FRAME 2
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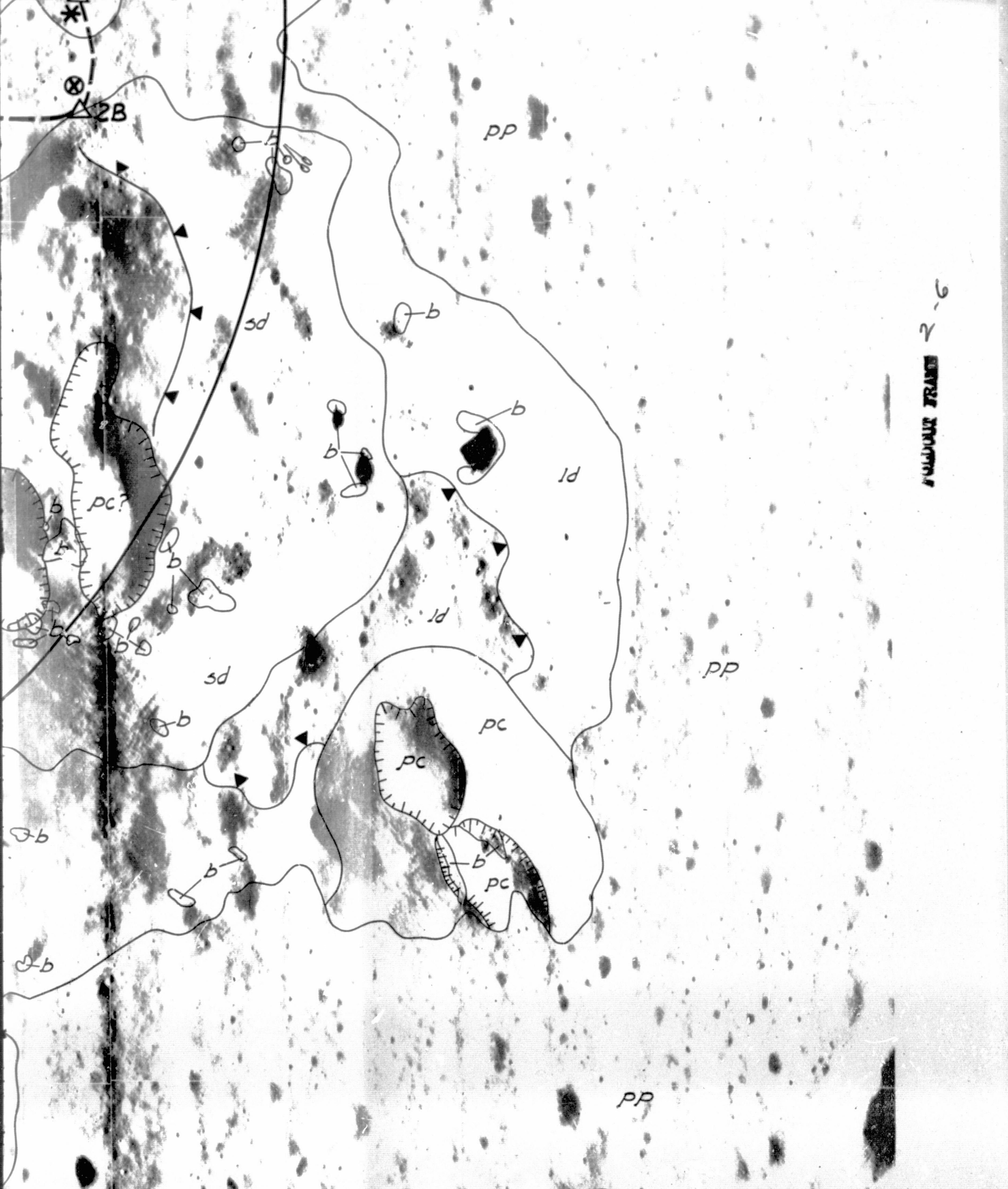

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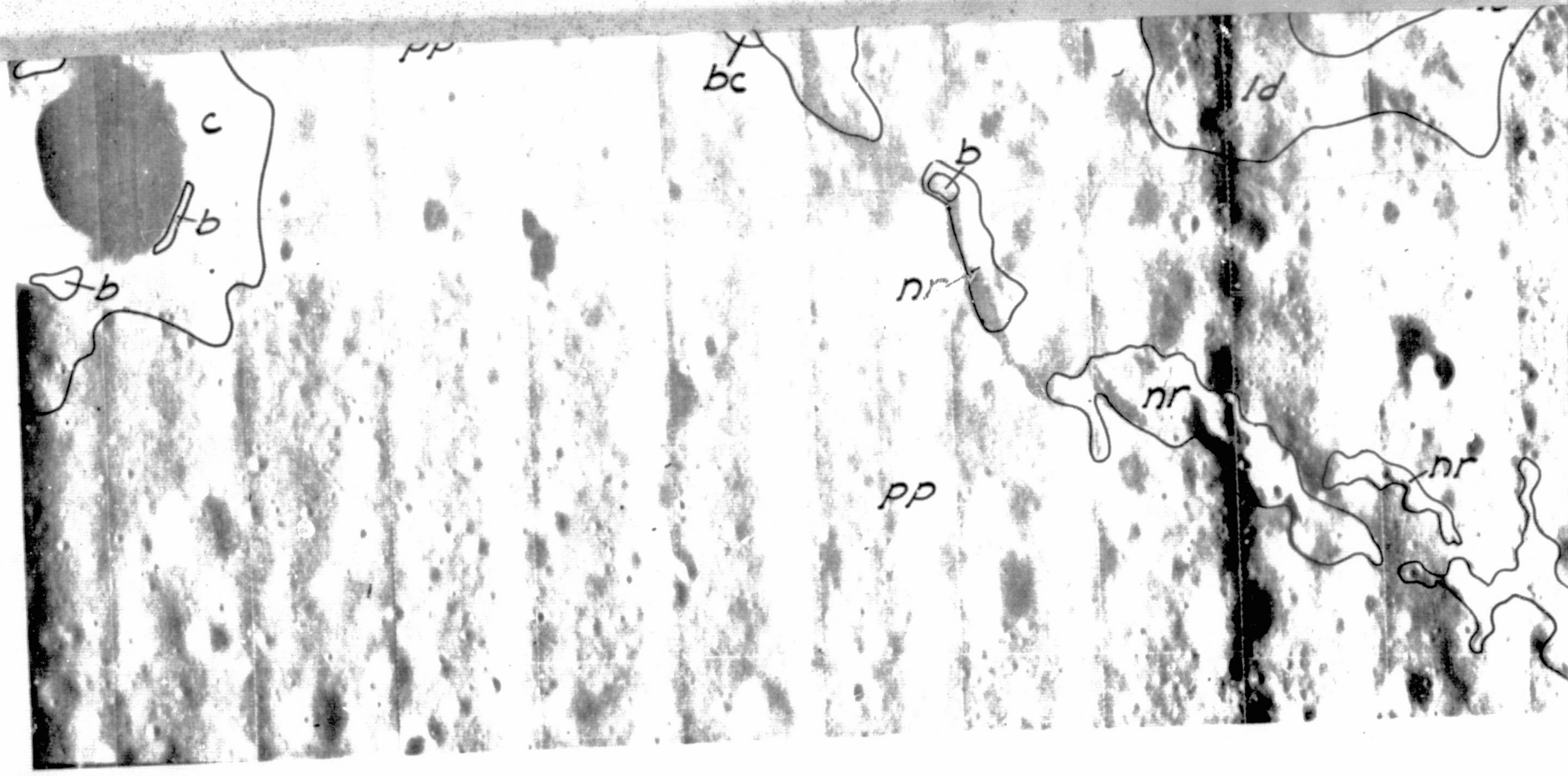

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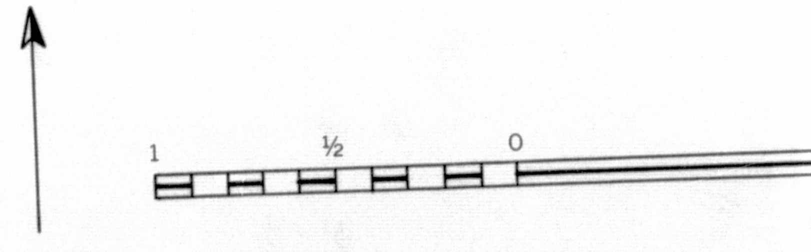
uncontrolled photomosaic

PRELIMINARY LARGE-SCALE GEOL



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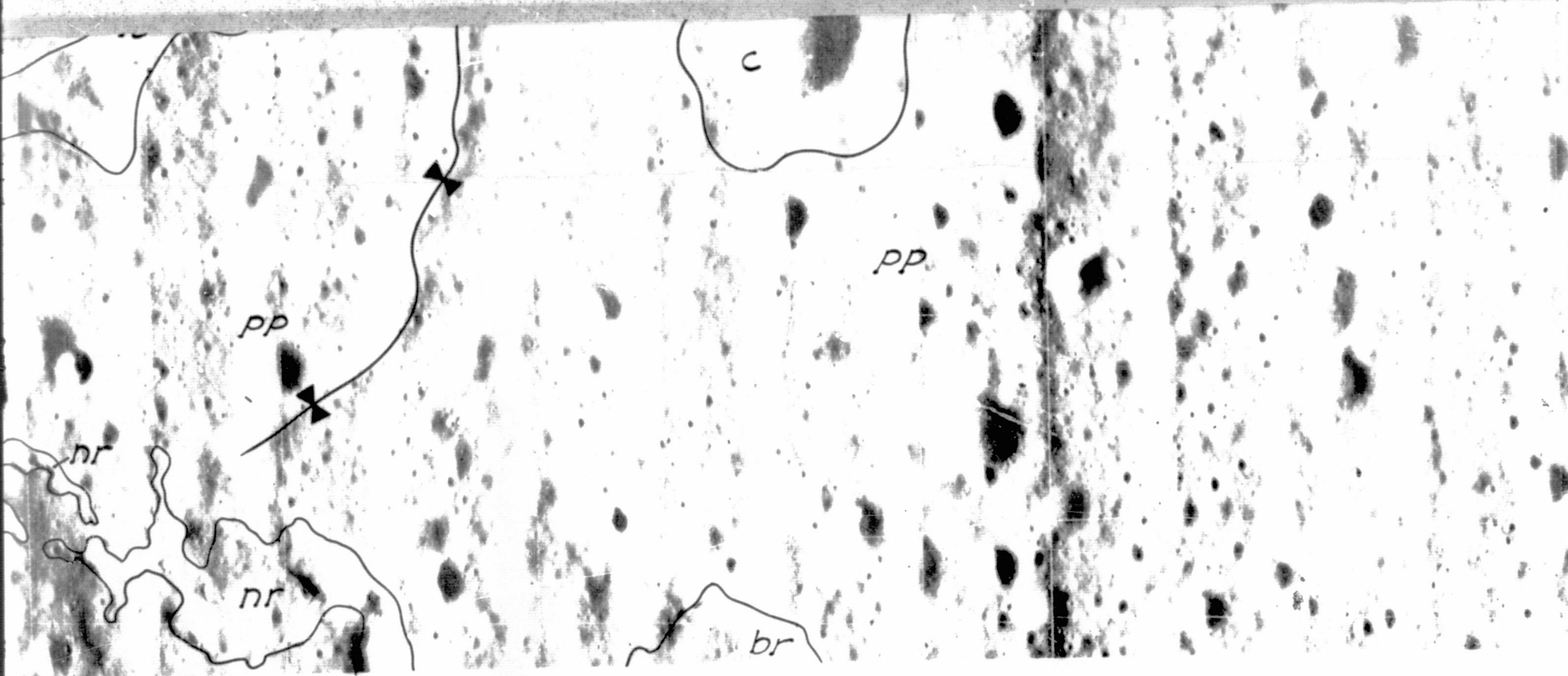

GEOLOGIC MAP OF PART OF THE MARIUS

By

John F. McCauley

1968

APP..OXIMATE SCALE 1:25,000

1 2 3 4 5 KILOMETERS

FOLDOUT FRAME 2-8

Geology mapped on Lunar Orbiter V photographs

ARIUS HILLS REGION

KILOMETERS

FOLDOUT FRAME 2 9

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FOLDOUT FRAME 3-1

nr

Narrow-ridge material

Material of steep-sided relatively small, narrow ridges; contacts mostly marked by scarps. Often superposed on broad ridge (br). Internal structure braided to en echelon in pattern. Locally appears to partly bury craters on the plateau plains (pp). Mostly viscous fissure flows; locally may be intrusive beneath impact regolith.

br

Broad-ridge material

Material of smooth-textured linear ridge of complex topographic form. Contact with adjacent plains marked either by gentle break in slope or by low scarp. Numerous smaller gentle scarps often occur within larger ridge. In southern and central part of map, trend is north-south; in north trend is north-northwest. Intrusive features which may, however, be locally extrusive. Probable surface expression of major deep seated north-south trending structures that interconnect the Marius Hills, Aristarchus Plateau and Rümker Hills.

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FOLDOUT FRAME 3-2

STRATIGRAPHIC UNITS

Marius Group

pc

Punctured cone material

Material of steep-flanked relatively smooth, conical structures having single to multiple linear depressions with intervening septa at or near the summits. Most cones and summit depressions are elongate in plan and oriented parallel to regional structure. Heights up to 300 meters above surrounding plains. Generally superposed on steep-sided domes (sd). Pyroclastic deposits surrounding structurally controlled vents. If features are analogs of similar appearing cones in Hawaii and other differentiated terrestrial volcanic provinces, the composition may be trachytic.

sd

Steep-sided-dome material

Material of steep-sided rough-textured domes generally perched upon low domes (ld). Contact marked by gentle to steep scarp; more rectilinear in plan than low domes. Heights generally from 200-300 meters above surrounding plains. Composed of numerous small ribs and spurs that are oriented north-northeast or north-northwest along the prevailing local structural trends. May be extrusive structures resulting from differentiation of the more primitive magmas that produced the mare material (m) and the low domes (ld).

bd

Bulbous-dome material

Material of smooth-textured domes; steeply convex upward in form. Smaller domes tend to be equidimensional; larger are more irregular and show influence of structural control. Intrusive or more probably extrusive structures formed from very viscous lavas of intermediate composition.

ld

Low-dome material

Material of smooth-textured gently tumescent structures as much as 100 meters higher than surrounding plains. Contact located at gentle break in slope. Convex upward in profile. Some roughly circular in plan. Most, however, are elongated in north-south direction. Lack of flow front morphology suggests a laccolithic origin.

pp

Plateau-plain material

Material of smooth to gently undulating cratered plains lying between domes and cones of Marius Plateau. Average elevation on the order of several hundred meters above the adjacent maria. Probably consists of volcanic flows, interbedded pyroclastic deposits and a moderately thick impact regolith.

Material in and
to overlapping
erally with sub
condary craters
Cavalerius.

FOLDOUT FRAME 3-3

FOL

TOPOGRAPHIC PROFILE

Vertical and Horizontal Sca

1:160,000

Crater units

bh

Bright halo crater material

Bright rim, interior slope, and floor materials of small widely separated craters. Material of relatively recent impact craters surrounded by bright blankets of pulverized bedrock and shock lithified regolith.

cc

Crater-cluster material

terial in and around clusters of closely spaced overlapping small to medium-sized craters, genally with subdued rims. Mostly material of sendary craters from Kepler, Aristarchus, and valerius.

c

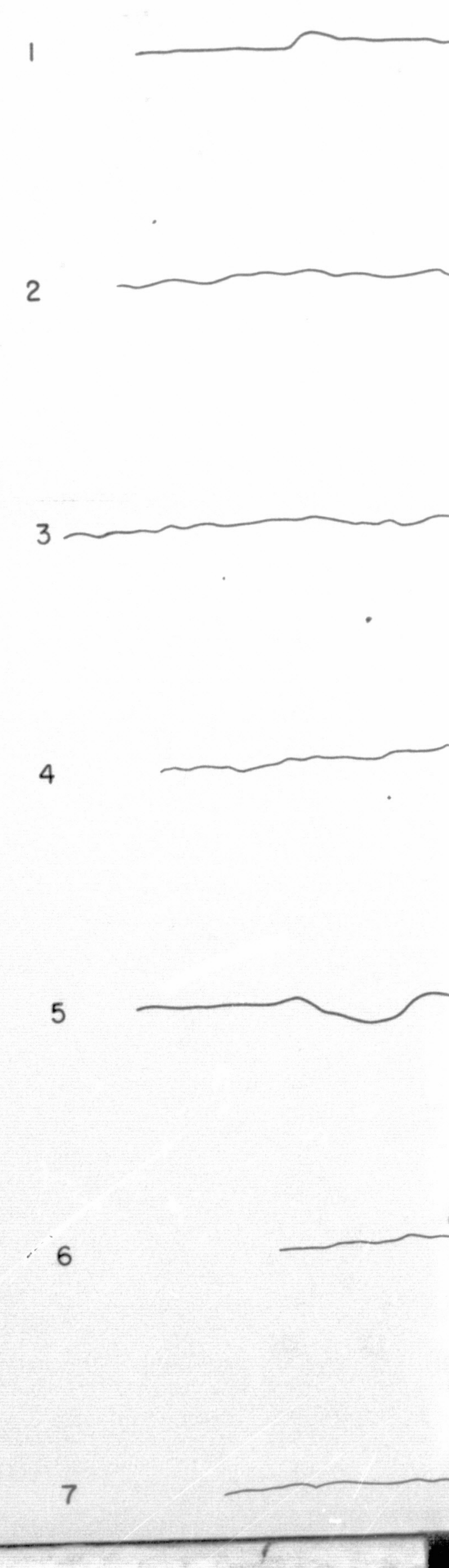
Crater material

Exterior rim deposits, interior slope, and floor materials of moderately subdued widely scattered craters. From crater lip to limit of rim deposit profile is concave upward. Mostly material of impact craters modified by later seismic and impact events.

bc

Crater material, partially buried

Subdued-rimmed crater material partly buried or overridden by narrow ridge materials (nr). Numerous craters of similar form are present on all units but are not mapped unless partly buried. Probably material of older impact craters degraded by micrometeorite bombardment and mass wasting.



INTERAGENCY REPORT: ASTROGEOLOGY 5

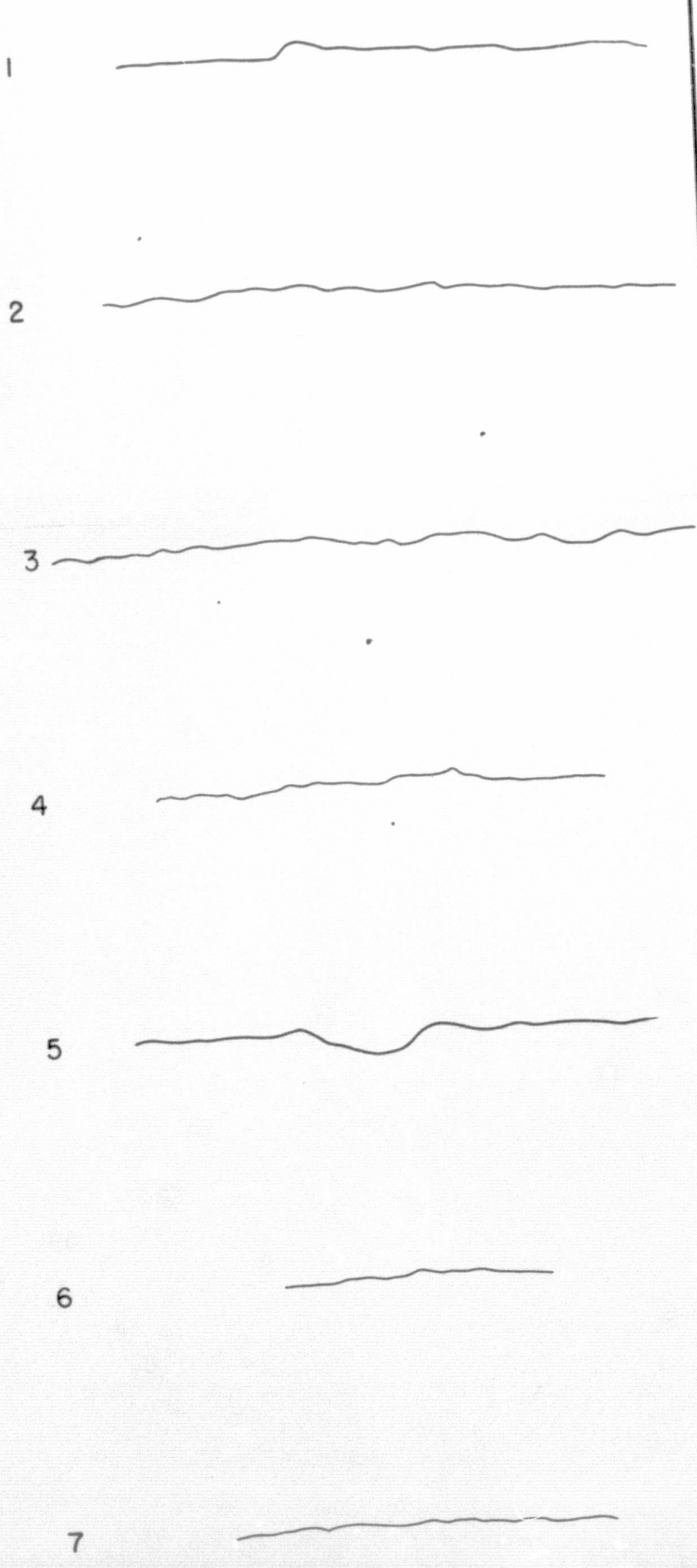
PLATE 3

FOLDOUT FRAME 3

TOPOGRAPHIC PROFILE

Vertical and Horizontal Scale

1:160,000



sr

Sinuous

Contact marks edge of sinuo
interior slopes and either
in the case of the largest
rather flat floor. Estima
about 0.2 meters per kilom
elevated rim that flanks p
example.

lt

Linear

Steep-sided linear depress
cular to elliptical depres

b

Bedrock or

Exposures of bedrock on st
block fields surrounding m

FOLDOUT FRAME 3-5

EXPLA

Dark mare plains material
(Procellarum Group)

m

Mare material

Dark cratered-plains material typical of the central regions of Oceanus Procellarum. Detailed descriptions contained in U.S. Geol. Survey Apollo site maps (1:25,000 and 1:100,000 scales) now in preparation.

sr srr

inuous rille

of sinuous depression with smooth either a "V" shaped profile or, largest sinuous rille, a broad Estimated gradient from high end r kilometer. Unit srr marks lanks part of the northernmost

lt

Linear trough

depression or closely spaced cir- depression.

b

rock or block field

ck on steeply sloping surfaces or unding moderately fresh craters.

Contact
Dashed where indefinite

Buried contact

Inferred fault

Subdued trough

Crest of scarp; barbs point downslope.

Rimless circular depression

Irregular summit depressions

5

Topographic profile line

FOLDOUT FRAME 3-6

LANATION FOR GEOLOGIC MAPS OF THE

8

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10

EXPLANATION FOR MISSION TRAVERSES SHOWN ON PLATE 2*

ELM
A
Landing site of Extended Lunar Module

—R-I—
Lunar Rover Vehicle (LRV) traverse

Extended Lunar Rover Vehicle traverse

—F-II—
Lunar Flying Unit (LFU) traverse

△2
Traverse station

Deploy communicator repeater

Deploy explosive charges for Active Seismic Experiment (ASE)

Deploy 3-geophone array for Active Seismic Experiment

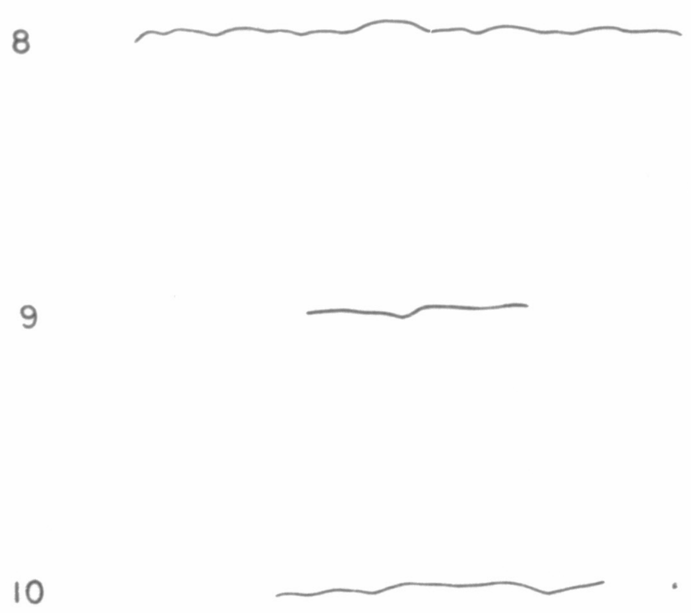
Deploy 8-geophone array for Active Seismic Experiment

Ⓐ
Deploy ALSEP

⊗B
Alternate landing area

*Prepared by T. N. V. Karlstrom, and G. A. Swann.

THE MARIUS HILLS REGION



FOLDOUT FRAME 3-f